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Synthetic Vision Systems (SVS)
Concept Assessment Report

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1.0 INTRODUCTION

This document supports work done under NASA Contract NAS1-00106 Task #1002, titled "Synthetic Vision Systems Concept Assessment and Flight Integration Planning". Specifically, efforts herein are intended to satisfy Deliverable Number 2 in the Statement of Work, titled "Concept Assessment Results Report for FY01". This document summarizes the efforts and inputs of a number of individuals on the Synthetic Vision Systems (SVS) Team from a number of industry and government organizations. It is a snapshot of results and findings from several Project activities, as they exist at the date of the document. Some of these activities are in progress as of the date of this document, or have final reports or analysis pending. Some results listed herein may change upon completion of the analysis and publication of final reports. Final results not summarized herein will be incorporated in the next SVS Concept Assessment Report, scheduled for the end of Fiscal Year 2002.

1.1 PURPOSE

The purpose of this document is to summarize experimental and study results, findings, and critical issues concerning the demonstrated or analyzed capability and potential of existing candidate SVS concepts in satisfying Commercial and Business (CaB) Transport Aircraft mission requirements.

1.2 BACKGROUND

1.2.1 Aviation Safety Program

In August 1996, following the wake of several high-visibility commercial transport accidents, a White House Commission on Aviation Safety and Security was established to study matters involving aviation safety and security. The Commission findings concluded that although the worldwide commercial aviation major accident rate is low and has been nearly constant over the past two decades, increasing traffic over the years has resulted in the absolute number of accidents increasing. Given the very visible, damaging, and tragic effects of a single major accident, this situation could become an unacceptable blow to the public's confidence in the aviation system. As a result, the anticipated growth of the commercial air-travel market would not reach its full potential. In February 1997, in response to the Commission's recommendations, President Clinton set a national goal to reduce the aviation fatal accident rate by 80% within ten years. NASA's role in civil aeronautics is to develop high risk, high payoff technologies to meet critical national aviation challenges. Currently, a high priority national challenge is to ensure U.S. leadership in aviation in the face of growing air traffic volume, new safety requirements, and increasingly stringent noise and emissions standards. NASA has a successful history of leading the development of aggressive high payoff technology in high-risk areas, ensuring a proactive approach is taken to developing technology that will both be required for meeting anticipated future requirements, and for providing the technical basis to guide policy by determining feasible technical limits. Therefore, NASA has stepped up to the challenge of addressing the President's national aviation safety goal by forming the new, focused Aviation Safety Program. As a first step to establish a focused safety program, NASA sponsored a major program planning effort to gather input from the aviation community regarding the appropriate research to be conducted by the Agency. This activity called the NASA Aviation Safety Investment Strategy Team (ASIST), held four industry- and government-wide workshops to define and recommend research areas, which would have the greatest potential impact for reducing the fatal accident rate. NASA then redirected existing research and technology efforts and formulated new ones to address the safety needs defined by ASIST.

1.2.2 Synthetic Vision Systems Project

One of the significant recommendations from ASIST was to establish a project to eliminate visibility-induced errors for all aircraft through the cost-effective use of synthetic/enhanced vision displays, worldwide terrain databases, and Global Positioning System (GPS) navigation. Therefore, on March 25, 1999 the Associate Administrator for Aerospace Technology, Spence Armstrong, signed the Project Formulation Authorization for the Synthetic Vision Systems Project. The Synthetic Vision Systems Project emphasizes the cost-effective use of synthetic vision displays (both tactical and strategic), worldwide navigation, terrain, obstruction and airport databases, integrity monitoring and forward looking sensors as required, and Global Positioning System-derived navigation to eliminate "visibility-induced" (lack of visibility) accident precursors for all aircraft and rotorcraft.

Studies concerning the SVS Project mission have been framed around, and developed, several candidate concepts (aggregate system and component characterizations) for satisfaction of mission requirements and reduction of technical and certification risk. Studies, simulation experiments, and flight test experiments have been devoted to exploring research issues associated with, and assessment of elements contained within, these concepts. The current document will summarize results from those studies and experiments, in terms of the demonstrated ability and potential of candidate concepts in meeting mission requirements.

1.3 SCOPE

This document is intended to be an upper level summary of results. Detailed study and test results may be found in the final reports of results for the individual experiments, rather than contained herein. Results are documented as they are known as of the date of this report. Results from reports released subsequent to this report date will be incorporated in the next update of this document, planned annually.

1.3.1 Components

For purposes of this task, the SVS Concept is assumed to consist of the following elements:

1.3.1.1 Sensors (or sensor equivalents)

- Forward Looking Infrared (FLIR) (potential)
- Multi-mode Radar (potential)
- Weather Radar (Potential SVS Modes)
- Millimeter Wave Radar (potential)
- Global Positioning System
- Onboard SVS Data Base
- System Integrity Monitoring
- Other Onboard Navigation Sensors and Data Bases (i.e., FMS, TAWS)

1.3.1.2 Displays

- Primary Flight Display, or imbedded display features
- Navigation Display, or display features/pages
- Head Up Display (option) with dedicated display features
- Pilot Information Display (potential)
- Interface with Other Cockpit Displays, i.e., TAWS

1.3.1.3 Equipment

- Dedicated SVS Support Equipment and Crew Interface
- Interface with Other Aircraft Systems

2.0 METHODOLOGY

Concept assessment has been conducted in conjunction with experiments and studies planned in CaB sub-elements within SVS. Where formal reports have been submitted, those results, as well as inputs from researchers and study participants are used to obtain assessment data. Where studies are in progress or final reports have not been released, interviews with researchers and study participants, or interim study data submittals are used to obtain assessment data. In the latter case, it should be realized that subsequent completion of data collection and analysis may change overall conclusions concerning concept suitability. In that event, new conclusions will be captured in subsequent updates of this document.

2.1 CRITERIA

As stated in the Synthetic Vision Systems Concept Assessment Plan, top level criteria for overall concept assessment include the following:

- Operational Performance. How does the concept perform in an operational environment, with respect to mission requirements and issues resolution? Metrics in this area will consist of quantitative performance data, and some (test and subject pilots and subject matter experts) qualitative opinion.
- Technical Feasibility and Risk. To what extent is the technology in the Calendar Year 2005 time frame expected to support technical requirements for the concept and its mission? What is the risk of overestimation in technology capability predictions? Metrics in this area primarily qualitative with supporting evidence, though technology readiness scales can be useful.
- Operational Risk. To what extent are limited operational performance results from current studies using concept elements expected to be applicable to a fleet of operational aircraft? What is the risk of error in expected acceptability in concepts and their elements to industry airline managers and flight crew? How susceptible are operational acceptability predictions to error? How well will components integrate with other cockpit equipment well into the design and implementation cycle? Metrics in this area will consist primarily of qualitative (albeit statistical) data, with supporting evidence.
- Marketing Risk. To what extent are concepts and their elements expected to be acceptable, in an intrinsic sense, to airline managers and passengers? How much more marketable and profitable is the aircraft using this concept and its elements expected to be? How susceptible are market predictions to error? Metrics in this area will consist of quantitative predictions, based on qualitative studies, hardware data, and experience with previous aircraft.
- Certification Risk. To what extent are concepts and their elements expected to be acceptable to airworthiness authorities for the purpose of commercial revenue service certification? How susceptible are predictions of certificability to error? A

Certification Issues Resolution Team has been formed by the SVS Project Team to help with assessments in this area.

2.2 METRICS

Specific metrics for use in each of the above areas include the following. Metrics are included in dedicated or shared studies, and used for assessment of each concept element, and the integrated concept assessment (of all elements and their interactions).

2.2.1 Operational Performance:

2.2.1.1 Flight Path Management

- Ground
  - Integrated Path Error (raw and threshold)
  - Maneuvering Reference (bldg, vehicle, hold short lines, etc) Errors
  - Workload Metrics (MCHR, etc)
  - Handling Qualities Metrics (CHR)
  - Effective Resolution (Color, Monochrome)
  - Situational Awareness (Judgment)
  - Quality Metrics (opinion, information content, clutter, aesthetics, etc.)
  - Physiological Metrics (heart rate, breath rate, eye movement, skin temperature, etc.)
  - Physiological Distress and Confusion

- Flight
  - Integrated Path Errors (raw and threshold)
  - Maneuvering Reference Errors (aircraft, terrain, airport features)
  - Flying Qualities Metrics (CHR)
  - Workload Metrics (MCHR, etc.)
  - Effective Resolution (Color and Monochrome)
  - Situational Awareness (Judgment)
  - Physiological Metrics (heart rate, breath rate, eye movement, skin temperature, etc.)
  - Physiological Distress and Confusion

2.2.1.2 Hazard Avoidance

- Ground

- Object Detection thresholds
- Object Maneuver Detection/Prediction
- Object Recognition Errors
- Escape Maneuver Errors
- Situational Awareness
- Crew Interaction
- Quality Metrics (opinion)

- Flight

  - Object Detection Thresholds
  - Object Maneuver Detection/Prediction
  - Object Recognition Thresholds/Errors
  - Escape Maneuver Errors
  - Situational Awareness
  - Crew Interaction
  - Quality Metrics (opinion)

2.2.2 Technical Feasibility/Risk:

- Established in the Literature
- Technical Readiness Level (TRL)
- Implementation Readiness Level (IRL)
- Lab/Field Demonstration
- Vendor Marketing Demonstration
- Subject Mater Expert Opinion

2.2.3 Operational Risk:

- Pilot Involvement/Opinion
- Potential User Involvement/Acceptance (Opinion)
- TRL/IRL
- Workshop Support

2.2.4 Marketing Risk:

- Market Studies
- Surveys
- Subject Matter Expert Opinion

2.2.5 Certification Risk:

- FAR Support
- Workshop Support
- Study Team Support
- Certification Issues Resolution Team (CIRT) Inputs

2.3 READINESS LEVELS

To clarify the overall assessment of a concept element in terms of its suitability for the CaB mission, the following technology and implementation readiness scales are adopted. The Technology Readiness Level refers to the readiness of the SVS component or element to support the CaB mission. The Implementation Readiness Level refers to the maturity of the SVS component or element with respect to operational use in the CaB fleet. These scales will be subsequently applied to concept elements, with respect to the overall criteria listed above in Section 2.1, to establish readiness levels.

2.3.1 Technology Readiness Level (TRL)

1: Basic Principles Observed and Reported
2: Technology Concept and/or Application Formulated
3: Analytical and Experimental Critical Function and/or Characteristic Proof-of-Concept
4: Component and/or Breadboard Validation in Laboratory Environment
5: Component and/or Breadboard Validation in Relevant Environment
6: System/Subsystem Model or Prototype Demonstration in Relevant Environment
7: System Prototype Demonstration in Operational Environment
8: Actual System Flight Qualified by Demonstration
9: Actual System Flight Proven in Operation

2.3.2 Implementation Readiness Level (IRL)

1: Technology Transfer Initiated
2: Industry R&D Funding Committed
3: Commercial Product Development Initiated
4: Application for Certification
5: RTCA/SAE or Equivalent Convened
6: Draft Certification Standard Developed
7: Certification Standard Established
8: Certification Approved
9: Operation of Certified System

3.0 STUDIES

Table 3.1 below, list studies and experiments commenced as of Calendar Year 2001, which are pertinent to the present Concept Assessment task. A summary of the study title, the type of study, and notes concerning status are included.

Table 3.1 SVS Related Studies and Experiments

Study	Type	Notes/Status
Tactical Terrain Awareness Concept Flight Evaluation (TIFS) - 09/99	Flight	Complete. Technical Highlight released
Initial Assessment of Size/FOV effects on Head-Down Tactical Retrofit Concept	Simulation	Tests complete for DFW and EGE.
Flight simulation evaluation of Tactical Terrain Awareness Concepts	Flight and Simulation	Initial tests complete, prior to and during DFW and EGE flight tests
Flight Evaluation of Limited Tactical HUD Concept for Flight Ops	Flight	DFW and EGE tests complete.
SA Tools for Retrofit Assessment –	Study	Complete. Report released
Advanced Display Media Technology Development	Study	In planning. Chief Scientist has summary. Pursuing procurement vehicles for several technology developments (some funding difficulties)
Simulation evaluations of Strategic EFIS Concepts	Simulation	In planning, Spring 2002.
Tactical SVS Concept elements in Challenging Airport Operational Environments - High Traffic, busy terminal area/airspace (DFW)	Flight	Complete. Technical Highlight complete. Subjective and objective data analysis nearly complete.
Data Integrity Monitoring Equipment EGE Flight Test	Flight	Complete
Tactical SVS Concept elements in Challenging Airport Operational Environments - Difficult Terrain (Eagle Vail)	Flight	Complete. Report in work.
SVS Ground Operations Study	Simulation	In planning
Integration of SVS/TAWS	Study/Flight	EGE flight test complete
Concept of Operations Study	Study	Complete
LMI Operations Benefits Study	Study	Complete

Study	Type	Notes/Status
BaE SVS Operational Benefits Study	Study	Complete
Runway Incursion Prevention	Simulation / Flight	Complete.
Hold Short and Landing Technology	Simulation / Flight	Complete
RADAR EVS Data Collection	Flight	Data collection and analysis ongoing
EVS FLIR Tests	Flight	Ongoing
SVS/EVS Retrofit In Airplanes With CRT Type Primary Flight Instrumentation	Study	Complete
LMI SVS Benefits Study Update	Study	Complete
BaE Enhanced Vision/Synthetic Vision Simulation	Simulation	Complete. Report in draft
Display Size and Terrain Texture Experiment	Simulation	In planning
SVS Compellingness Study	Simulation	In planning

4.0 STUDY SUMMARIES

The following are summaries of significant findings for each of the studies which were completed or are in progress this Calendar Year, which relate to concept assessment.

4.1 Tactical Terrain Awareness Concept Flight Evaluation (TIFS) - 09/99

- The purpose of the research was to conduct flight evaluations of a state-of-the-art photo-realistic terrain database and NASA LaRC Synthetic Vision Tactical Concept display
- Evaluations were conducted from the "terrain impacted" Asheville airport on October 11-15, and November 2-4, 1999, in 16 flights, with over 60 various types of approaches, 4 to touchdown.
- Flight demonstrations featured image comparisons of external video from an High-Definition Television (HDTV) camera with overlaid flight symbology displayed head-up on a 13" x 18" projection system to a synthetic vision scene, with overlaid symbology displayed both head-down on a 8" x 10" LCD and head-up on a 10" x 18" projection system in various size renditions (size A, D, and full screen size).
- For each display size, 4 minification levels -unity, 30° horizontal field of view (HFOV), 40° HFOV and 60° HFOV- were available for presentation on the tactical display.
- The tactical synthetic vision scene incorporated terrain, obstacles, flight symbology, airport features (runway, taxiways, tower, FBO, etc.), and air traffic icons.
- A Navigation Display (ND) was also employed to assist flight test maneuver execution.
- Forty people attending the Aviation Safety Program (AvSP) Synthetic Vision (SV) kickoff meeting participated in ten demonstration flights.
- In addition to the flight demonstrations, the AvSP SV held a two-day meeting in Asheville, NC, to kickoff eight unique SV project cooperative agreements with industry and academia. There were more than seventy meeting attendees from over twenty-five diverse organizations including DOD, FAA, NIMA, and Airline representation.
- NASA personnel provided a summary of the five-year, $100 M Synthetic Vision Project plan and each NASA Research Announcement cooperative agreement team provided an overview of their proposed effort.

4.2 Initial Assessment of Size/FOV Effects on Head-Down Tactical Retrofit Concept – 06/00

- The purpose of this simulation experiment was to determine whether useful and effective Synthetic Vision System (SVS) displays could be implemented on limited size display spaces as would be required to implement this technology on older aircraft with physically smaller instrument spaces.
- Prototype SVS displays were put on the following display sizes: (a) size "A" (e.g. 757 EADI), (b) form factor "D" (e.g. 777 PFD), and (c) new size "X" (Rectangular flat-panel, approximately 20 x 25 cm).
- Testing was conducted in a high-resolution graphics simulation facility (VISTAS I) at NASA Langley Research Center.
- Specific issues under test included the display size as noted above, the field-of-view (FOV) to be shown on the display and directly related to FOV is the degree of minification of the displayed image or picture.
- Simulated approaches to runways at Asheville, NC, (mountainous terrain) and at Dallas-Fort Worth airports were used.
- Variables assessed included precision of handling piloting task, errors, and nature of errors, answers to Situation Awareness probes, workload and ease of handling piloting tasks, effect of disruptive events (changes, communications), pilot ratings and rankings of display concepts, and pilot comments
- Results show that small display spaces, while not the preferred size, may be utilized without positional performance penalties when raw horizontal and vertical guidance information is present. Future studies will have to be conducted to investigate the efficacy of photo-realistic terrain versus other types of distance and depth cueing, especially when small display spaces are used.
- Results also showed that FOV requirements appear to be a function of information needs of pilot depending on phase of flight. Small FOVs may have display issues of small pitch scale angle shown and potential for flight path vector to be significantly displaced in cross-wind conditions. How to change FOVs is another issue to consider when varying of FOVs is considered.
- Results indicated:

    Pilot preferences for optimal Field-of-View were varied and phase-of-flight dependent

Two most preferred FOVs were Unity and 30 deg

- Selected Pilot Comments:

  "Unity is too sensitive to heading changes in turn, 30 deg is best overall."

  "I would use 90 deg for VMC conditions and unity for IMC approaches."

  "Unity has most precise detail for approach, good FOV with the big display. 90 FOV gives widest look as you begin turns. Have a better feel for the overall terrain."

  "I can see a tremendous benefit to a larger FOV during the en-route phases of flight especially in mountainous terrain.

  "Great concept—looking to see it soon."

4.3 Flight Simulation Evaluations of Tactical Terrain Awareness Concepts – 09/00 To 12/01

- The purpose of the study is to assess effective Synthetic Vision Presentation on Tactical Displays (PFD/HUD) using flight test research and simulation facilities.
- Issues include varying display sizes, optimum field of view (FOV) for small displays, size A and D, in retrofit aircraft, optimum FOV for larger formats in forward-fit aircraft, FOV/minification tradeoffs, display size and pixel count (resolution) issues, effect on pilot workload as compared to conventional PFD, operational benefits of having elevation/obstacle database, safety benefits/limitations, integration with out-the-window scene transition / training issues, clutter.
- Test desirable FOVs for converging approaches and parallel approaches/departures, circling approaches.

4.4 Flight Evaluation of Limited Tactical HUD Concept for Flight Ops – 09/00

- The purpose of the study is to assess effective Synthetic Vision Presentation on Tactical Head-Up Displays using flight test research facilities.
- Testing Considerations include how to display information – opaque SV photorealistic scene / wireframe, minification utility, operational benefits of

using HUD with database, safety benefits/limitation, declutter techniques – manual or automatic, how to avoid clutter, increases in SA – look at different facets of SA, including spatial, systems, etc; effect on pilot workload, integration with out-the-window scene, and transition / training issues.

- Tests at DFW complete. Results pending.
- Tests at EGE complete.
- From 20 August to 9 September, 12 research flights totaling 51.6 flight hours were flown. Seven (7) evaluation pilots, representing 3 airlines, the FAA, NASA, and two pilots from Boeing, performed evaluations. 87 runs were conducted to evaluate the NASA display concepts of which 52 were flown to Runway 07 and 35 were flown to Runway 25.
- Results show a noticeable improvement in terrain awareness by the SV-HUD concept. Data also show that the SV-HUD concept, like the baseline concept, is not universally effective in providing terrain awareness.
- NASA research activities are now being directed to evaluate scene rendering techniques, HUD brightness capabilities, and scene augmentation techniques to mitigate SV-HUD concept deficiencies noted, with respect to brightness, and scene artifacts.

4.5 SA Tools for Retrofit Assessment – 09/00

- The purpose of the study was to develop a set of tools to use in situation awareness measurement of retrofit display media Synthetic Vision concepts.
- Under contract to NASA Langley, Dr. Mica Endsley completed review of relevant SA measures for SVS and documented these in report SATECH-00-11, June 2000, entitled: Evaluation of Situation Awareness in Flight Operations Employing Synthetic Vision Systems. Report includes details on each methodology and candidate questions or probes for simulator and flight experiments.
- Scenarios developed and utilized for Size and Field-of-View laboratory experiments.
- Future Work: Tools, techniques, procedures, and scenarios developed will be employed in future simulator and flight experiments. Additional assistance by Dr. Endsley anticipated.

4.6 Advanced Display Media Technology Development – 10/00 To 03/03

- Contracted studies to develop potential future media technology with applications to SVS displays.
- Study is in planning.

4.7 Simulation Evaluations of Strategic EFIS Concepts – 10/00 To 09/01

- The purpose of this simulation experiment is an assessment of Synthetic Vision System elements associated with strategic displays (i.e., Navigation Display) or strategic elements of tactical displays (i.e., PFD).
- Issues include display control issues for PFD-SVS and/or ND, location of controls for SVS / enhanced ND, integration with tactical displays (SV PFD and/or HUD), integration with out-the-window scene – transition / training issues, increases in SA – look at different facets of SA, including spatial, systems, etc; effect on pilot workload as compared to conventional ND, operational benefits, safety benefits/limitations, and clutter.
- This experiment is in the planning stage, with evaluations planned in the Summer of 2001.

4.8 Tactical SVS Concept Elements in Challenging Airport Operational Environments - High Traffic, Busy Terminal Area/Airspace (DFW)

- The purpose of this flight test research experiment was to evaluate NASA concepts to address retrofit issues and explore display parameters, and evaluate a Rockwell-Collins head-down concept (aimed at near-term implementation using current avionics)
- Display parameters evaluated included HUD terrain database texture types (generic, photo-realistic), Head-Down Display (HDD) sizes (A/B, D, X), terrain database texture types (generic, photo-realistic), and selectable Field of View (FOV)
- HUD tests evaluated an unconventional use of a HUD for both VMC and IMC operations
- HUD imagery provided an opaque, computer-generated terrain scene, in front of the real world ground scene, with the sky portion of the scene unobstructed by imagery.
- A declutter switch was evaluated and used to view the real world (when desired or at decision height)

- Certification issues about obscuration of real world are a recognized concern
- The SVS Research Display (SVSRD) for this test was a large, 18.1” High-Brite LCD display with touch screen and brightness control, capable of displaying head down A/B, D, X formats, and SXGA resolution.
- The display was designed for easy (10 second) inflight removal
- The SVS Graphics Engine consisted of two Intergraph Zx1 PCs, with dual 800-MHz processors, 1 Gig of RAM, and Wildcat 4110 Video boards with 268 MB of Texture memory
- Less than $10,000 per PC!
- The scope of tests included six evaluation pilots, 17.5 hours of research time, with 76 total approaches
- Pilot comments indicated that the opaque terrain image on HUD was widely accepted for night operations
- Judging distance and closure rates seemed better with Photo-realistic terrain
- Larger FOV of HUD at unity magnification, and being head-up were positively reflected in pilot’s comments when compared to HDDs
- Collimation aspect of HUD enhanced 3-D effect of terrain image
- All pilots preferred using selectable Head Down Display FOVs
- Larger FOVs prior to final (~60 degrees)
- ~25-45 deg FOV used for runway change
- Smaller FOVs close-in on final approach (~30 deg or less)
- Larger displays preferred over small
- NASA Opaque image on HUD appears viable for retrofit (at least for night operations)
- Synthetic vision appears to be effective on all display types evaluated (Size-A/B, D, X, and HUD), with some complaints that the resolution on the Size A display was low.
- Rockwell-Collins concept considered effective & fairly mature
- All pilots preferred availability of multiple FOV selection
- All pilots acknowledged the enhanced situational awareness provided by synthetic vision, regardless of the SVDC size/type

4.9 Data Integrity Monitoring Equipment EGE Flight Test

- The goal of the flight test was to gather data to help define required architecture and component technologies, to assure adequate integrity for the envisioned operational uses of SVS.
- 119 test runs were completed at EGE (Aug 19 – Sep 9, 2001). 87 test runs yielded complete data sets needed for assessments. Each run consisted of three segments: approach, runway overfly, departure.
- On-going assessments are being applied to four terrain databases - both against each other, and against sensor measurements: DTED Level 0 product (30 arc-second, 900m resolution), USGS 1 degree product (3 arc-second, 90m resolution), USGS 7.5 minute product (1 arc-second, 30m resolution), and NGS product (5m resolution).
- Sensor data used included three radar altimeters, WAAS performance characterization, and INS performance characterization.
- Tests achieved goals. Data showed good agreement in data sources, within test assumptions.

4.10 SVS in Challenging Airport Operational Environments - Difficult Terrain (Eagle Vail)

- Completed in early Fall 2001
- Six NASA Synthetic Vision display concepts were tested over a 3 week period to evaluate tactical Synthetic Vision display concepts in a terrain-challenged operating environment, including concepts for HUDs and HDDs ranging from ARINC Standard Size A through Size X. Seven pilots evaluated these displays for acceptability, usability, and situational/terrain awareness while performing existing commercial airline operating procedures.
- Evaluations were also flown for a baseline display configuration, simulating the EFIS with TAWS display typically flown in present-day operations.
- The goals and objectives of the SVDC-EGE flight test were generated by the SVDC flight test team in response to the SVS project and established project plan and milestones.
- In general, EGE testing extended assessment of the SVS retrofit approach to operations in a realistic terrain-challenged operational environment
- Testing assessed the potential of NASA Opaque HUD / Clear Sky Concept as a retrofit solution for display of SVS concepts in non-glass cockpits, and determined potential in both day VMC and day, low-visibility operational environments.

- Testing confirmed results from piloted simulation experiments and SVS-DFW flight test for operational utility and acceptability of various sized (size A/B, D, X) synthetic vision displays for retrofit into existing glass cockpits.
- Testing compared the operational utility and acceptability of photo-textured with conventionally-textured terrain database SVS concepts within NASA SV concepts (HUD; head-down size A/B, D, X).
- Testing investigated the operational utility and acceptability of enhanced terrain awareness of SV display concepts to RNP approach procedures in a terrain-challenged operational environment.
- Testing assessed pilot path control performance during manually flown landing approach and go-around maneuvers in a terrain-challenged operational environment, with and without SVS display concepts, and determined the effect on that performance of the presence of SVS components.
- Testing assessed autopilot monitoring utility and operational acceptability of SVS display concepts in a terrain-challenged operational environment.
- Testing assessed the utility and interpretability of TAWS, incorporated in an SVS concept, a terrain-challenged operational environment.
- Testing assessed the operational utility and maturity of Rockwell/Collins SVS concepts in a terrain-challenged operational environment.
- Subjective measures of terrain awareness for the head-down display SV concepts were significantly improved over the baseline EFIS with TAWS display configuration.
- Particularly for the Size X SV-HDD, pilot confidence in terrain information was dramatically improved over the baseline EFIS with TAWS display configuration.
- Data show that the addition of SV terrain did not create a clutter problem. In fact, the baseline display condition was rated poorly because the amount of information was insufficient to do the task. The SV terrain and other associated guidance information were necessary to perform the EGE approach and departure task. SV Size X display configurations were unanimously ranked as providing the highest level of situational awareness of the display configurations tested and the baseline configuration, the least.
- Data show a ranking preference for the photo-realistic texturing in all display media applications in promoting situational awareness, but these findings have not yet been proven statistically significant.

4.11 SVS Ground Operations Study

- The purpose of this study is an investigation of issues associated with integration of Surface Operations Display Concepts with Airborne Display Concepts
- Testing Considerations will include integration of both tactical (PFD/HUD) and strategic (ND) displays, and the development of tactical and strategic display switching strategies (gradual, instantaneous, certain altitude) from surface to air (departure) and from air to surface (landing) display concepts.
- Efforts here will build upon display work developed under AvSP's Runway Incursion Prevention Systems and TAP's LVLASO program.
- The study will investigate industry surface operations display concepts and incorporate into ND/PFD/HUD SVS concepts where appropriate
- The study will investigate surface operations display concepts associated with the FAA's SafeFlight 21 and Runway Safety Programs
- This study is in planning

4.12 Integration of SVS/Terrain Awareness System (TAWS)

- The purpose of this study and flight test experiment will be to investigate issues associated with integration of SVS with TAWS
- Testing Considerations include the best use of low resolution TAWS, Weather RADAR, and high resolution SVS, obstacle presentation in TAWS, and terrain awareness comparisons between TAWS and SVS, and safety and operational benefit comparisons between TAWS and SVS.
- The study and experiment will consider approach, takeoff, missed approach.
- Scenarios will include a Cali-like CFIT accident (descent)
- This test is in planning for Spring, 2003.

4.13 Concept of Operations Study

- The purpose of the study and workshop held on February 23-25, at the NASA Langley Research Center, was to bring together 65 industry, FAA, and NASA representatives for discussion and development of concept of operations (CONOPS).

- Provided feedback to support the creation of a CaB and GA SVS CONOPS document, (milestones 6/30/00, 4/30/00).
- Attendees worked toward defining the CONOPS elements, applications, benefits, capabilities, and a list of areas for SVS research.
- The workshops succeeded in initiating open discussions of the operational applications of synthetic vision technology. New concepts and perspectives were discussed and will be used to guide the Synthetic Vision team's focused research and shared research with our Cooperative Agreement Partners.
- These workshops are critical in forming solid industry/government exchanges and collegiate relationships. This kind of team activity will help to ensure the success in the achievement of the Aviation Safety Program Goals.
- Future Plans: The NASA CONOPS team will write a preliminary CONOPS document from the discussions from the CaB workshop. This CONOPS will be circulated throughout the industry and government for comment.

4.14 LMI Operations Benefits Study

- The purpose of the study was to estimate the economic impact of the SVS capabilities to provide input to the NASA SVS Concept of Operations (CONOPS) document.
- Synthetic vision systems should provide several improvements in airport terminal area operations. Among these are reduced arrival and departure minimums, use of additional multi-runway configurations, independent operations on closely spaced parallel runways, and reduced arrival spacing.
- Using modified versions of airport capacity and delay models previously developed to analyze other NASA technologies, the study estimated how much these improvements would reduce arrival and departure delays.
- The analysis results indicate that SVS technologies should provide large economic benefits, but that different capabilities are important at different airports.
- The results indicate that the ability to conduct circling and converging approaches will provide major benefits at two key airports (Chicago, Newark).
- Reduced arrival separations are essential at two other key airports (Atlanta, Los Angeles).

- The remainder of the capabilities provides significant, but lesser, benefits. The ability to conduct low visibility ground operations at normal visual tempo is an essential enabling capability for all benefits. The priority for research of the SVS Concept in surface operations should be increased.
- Recommendations for future SVS testing included converging and circling operations in IFR Cat IIIb conditions, autonomous aircraft approach positioning with respect to leading aircraft, arrival and departure operations under conditions of zero foot ceiling and 300-foot runway visual range (RVR) with a goal of demonstrating operations at zero foot RVR, ground operations at visual flight rule tempos with visibility as low as 300 feet.
- Tests and analysis should include determining the minimum operational hardware requirements for each of the capabilities above, specifically, whether a head-up display is technically required for each capability, and the minimum hardware suite necessary to provide FAA-required system performance and reliability.

4.15 BaE SVS Operational Benefits Study

- Operational and economic analysis as part of BaE's Phase I effort.
- Results show that the economic paybacks for an SVS system were largely the result of increased system throughput as more VMC-like operations would be permitted with the use of aircraft with SVS systems.
- SVS with EVS can potentially significantly reduce the throughput delays caused by low visibility at major airports
- SVS with EVS can potentially maintain VMC efficiencies of multiple runways
- SVS with EVS can potentially eliminate below-minimum conditions for landings and takeoff.
- SVS with EVS can potentially maintain VMC equivalent taxi operations in low visibility IMC.

4.16 Runway Incursion Prevention

- The purpose of this simulation and flight test research experiment was to assess and validate technology performance for preventing runway incursion accidents, and collect data to assess the performance of the emerging incursion alerting algorithms, data link, GPS, and surveillance technologies.
- Included was a validation of system performance data against evolving RTCA standards for data links, LAAS/WAAS, surveillance, and databases

- An attendant goal of the flight test efforts was to demonstrate the system in an operational environment, both during tests, and in a separate effort for industry and regulatory representative observers.
- The flight test associated with this experiment integrated with the FAA Runway Incursion Reduction Program's (RIRP) DFW surface surveillance infrastructure
- Three methods of generating runway incursion alerts were used – an aircraft based alerting algorithm developed by Rannoch (RIAAS), an aircraft based alerting algorithm developed by NASA (RSM), and an algorithm using alerts generated by FAA surveillance system and transmitted to aircraft (GBS). Each method was evaluated simultaneously, and one source chosen for display in cockpit
- Tested scenarios involved real incursions by ground intruder vehicles (van and truck).
- 4 airline captains were used as subject pilots. 51 RIPS test runs were conducted (in addition to checkout runs).
- Results indicate that pilots felt safer with RIPS onboard, felt RIPS alerting was timely. Pilots were impressed with Electronic Moving Map for surface situational awareness.
- This flight test demonstrated the feasibility of providing aircraft based runway incursion alerting.
- The missed alerts for RSM and RIAAS were a direct result of erroneous or missing traffic data from the STIS-B and/or ADS-B sources. It should be noted that during the testing, RSM was scanning all traffic for potential conflict while RIAAS was only tracking the test van.
- For GBS, the missed alerts were the result of the GBS alerting criteria and scenario timing.
- For the approach scenarios, generally the RIAAS RTA occurred a few seconds before the RSM alert. Usually eight to 10 seconds later, the GBS alert was generated.
- All of the subject pilots were complimentary of the RIPS tested at DFW. The pilots stated that the system has the potential to reduce or eliminate runway incursions, although human factors issues must still be resolved.
- Several suggestions were made regarding the alerting symbology which will be incorporated into future simulation studies.
- The Runway Incursion Prevention system tested at DFW demonstrated the potential to reduce or eliminate runway incursions.

4.17 Hold Short and Landing Technology

- The purpose of this flight test and simulation experiment was to assess and demonstrate the utility and acceptability of hold short and landing technology during approaches and landings in a representative transport class aircraft.
- A total of twenty (20) test runs were made to assess the performance and suitability of the HSALT system for conducting LAHSO. Twelve runs were made specifically to assess if the HSALT Stopping Factor (SF) was suitable for judging if a LAHSO should be performed. Eight runs were made assess the timing and suitability of the automatic changing of the guidance to the next exit by the missed-exit logic.
- Symbology was provided before landing to provide the pilot with information on the HUD & ND for judging the difficulty of stopping at hold short location; information was provided in the form of a Stopping Factor (SF), and a runway plan view with exits & hold short location on ND
- Symbology was provided after Landing on the HUD to provide the pilot deceleration information/guidance for stopping at hold-short location or decelerating to turnoff speed of earlier exit, and provide the pilot continual situational awareness on criticality of stopping the aircraft at the hold-short
- All subject pilots were able to stop at or before the hold short location for test runs with SF equal to 1 (values greater than 1 are intended to advise that a LAHSO should not be performed). The pilots indicated that the deceleration level needed to stop at the hold short location with SF equal to 1 was reasonable. Thus, the tests indicate that SF is a reasonable indicator to judge if a LAHSO should be performed when the pilot is requested to conduct one.
- The pilot comments indicate that the timing for switching to another exit or hold short location needs additional development. Two pilots indicated the switching was too late and two that it was reasonable. One questioned whether the switching function was useful and one indicated that it seemed difficult to determine what exit had been sequenced to.
- All the pilots like the deceleration guidance with all scoring the deceleration bar as very useful. The overall response to a query in the pilot questionnaire on whether the deceleration bar and football were redundant was that the deceleration bar and football were both useful.
- Pilots also expressed that HSALT has applications well beyond land and hold short (LAHSO) operations, including rollout & turnoff for reduced runway occupancy time, contaminated/wet runway operations, and rejected takeoff

4.18 RADAR/FLIR EVS Data Collection

- Objective at DFW was to collect RADAR data relevant to Runway Incursions using experimental X-band weather radar.
- Twelve days of Runway Incursion data were collected on 60 CDs.
- These data will be useful in the testing of existing detection and tracking algorithms and should provide significant insight for future algorithm development.
- Further data acquisition at Eagle-Vail Summer / Fall 2001
- The Eagle-Vail flight tests permit the acquisition of actual RF sensor data for direct application to potential hazard detection algorithms.
- Experimental X-band weather radar data, dual band FLIR data and CCD derived visual data collected.
- Testing to collect RADAR data and FLIR/visible-band imagery during terrain-challenged operations to enable object detection and terrain feature extraction algorithm development and refinement for independent integrity monitoring applications.

4.19 EVS FLIR Tests

- Conducted at Wallops and Eagle-Vail, Summer and Fall of 2001.
- Testing gathered data for algorithm development, and assessed landing approach operational utility and acceptability of enhanced vision system concept (FLIR sensor image) in a realistic operational environment. Note, this objective does require a supporting terrain database, and as such is site independent.

4.20 Candidate Concept Description for SVS/EVS Retrofit in Airplanes with CRT Type Primary Flight Instrumentation

- Describes a phased approach to achieving SVS capabilities in a retrofit implementation of the candidate concepts, into airplanes that have CRT type of primary flight instrumentation.
- Only approximately 34 percent of the commercial transport airplane fleet currently in service have CRT/LCD type of display technology (with a very small number being LCD equipped – the rest have mechanical instruments).

- Retrofit issues for the CRT equipped airplanes make this approach for SVS/EVS implementation extremely problematic. There is no excess graphic capability in most of the currently flying graphic generators.
- Without a significant upgrade to the existing equipment, the SVS/EVS tactical functions are not achievable on the head-down displays.
- The industry is moving towards an LCD upgrade to both and-on and retrofit airplanes. This upgrade would provide the opportunity to incorporate the SVS/EVS functionality in head-down displays.
- The positive side of this strategy is that the SVS/EVS will not have to absorb the cost of the upgrade in its cost/benefit justification. The down side is that the implementation will be prolonged to such an extent that it will have little impact on the safety goal.
- A phased implementation strategy is recommended, in which low risk capability additions are the focus of the initial efforts, and the higher risk functionality phased in at a later date.
- Low risk system components that would be incorporated in addition to those in the Basic Concept include: Differential Global Position System (DGPS); TAWS Plus; enhanced terrain database to provide higher fidelity and more expansive coverage of the terrain; enhanced airport database providing the airport surface information as well as the runway information; system integrity monitoring; datalink of the taxi clearance; enhanced weather radar to detect runway incursions; and a ground-obstacle detection capability. As with the Basic Concept, the HUD would be the Primary SVS/EVS tactical display, the existing head-down EADI/PFD would be the Primary Flight Display, and the head down EHSI/NAV display would be the in-air strategic planning and navigation display and on the ground the airport moving map display.
- Capabilities provided by the near term concept include: flight operations into any runway in visibility conditions down to and including CAT IIIa visibility; depiction of runway stopping performance; detection and prevention of runway incursions; and enhanced low visibility and congested area taxi.
- Long term, high risk component additions would include: LCD EFIS upgrade; SVS/EVS capable symbol generators; fail operational system architecture; textured/photo realistic terrain and airport display formats; high fidelity/resolution databases; enhanced TCAS/CDTI; enhanced obstacle/hazard detection sensors; capability to fuse data from multiple detection sensors; components that will perform SVS/EVS computational functions; system integrity, verification and validation function.
- Capabilities provided by the long term system concept would include: flight operations into Type II certified facilities in visibility conditions down to and

including CAT IIIb; operations using Visual Flight Rules in IMC Flight operations in CAT IIIb; low visibility approaches to be performed without a decision height, which means that the flight crew does not have to visually acquire the runway environment in order to perform the landing.

- An extension of the long term concept refining the technology and gaining in-service experience with the system could result in achieving the goal capability which is VFR operations in all visibility conditions at all airports.

4.21 Updated LMI Study on SVS Benefits

- LMI's previous analysis estimated the benefits of SV for 10 major airports, using estimates for airport capacity and delay models for estimating the benefits of the NASA Terminal Area Productivity program.
- In this effort, LMI addressed the following tasks: 1) Update the current capacity and delay analysis based on industry input; 2) Estimate the benefits of reducing ceiling and visibility minimums for arrivals and departures at additional airports; (3) Analyze SVS economic benefits for feeder and cargo operations, and (4) Analyze SVS economic benefits for business operations.
- Airport scenarios assessed were Juneau (JNU), San Diego (SAN), Eagle County/Vail (EGE), Washington Reagan (DCA), and Sacramento (SMF).
- Benefits for three SV technologies were compared, based on operational capability. Differences were applied to discover benefits of potential lower departure and arrival minima, Cat II and III operations at all runways, special IFR converging and circling operations, reduced separation and runway occupancy time, and independent parallel runway operations, in a 2005 baseline (BL) technology.
- Results of the study indicate that the primary benefits at JNU, SAN, and DCA are gained with the capability to use runways and approaches that are currently limited by high ceiling and high visibility minimums during inclement weather conditions. Additional visibility minimum reductions to 300 feet for arrivals and departures, and reductions in miles-in-trail spacing provide marginal improvements.
- The benefits for SMF are relatively small, and appear to derive from the reduction of visibility minimum from 600 feet to 300 feet.
- Implementation of basic SVS technology essentially eliminates delays at EGE.

4.22 BaE Enhanced Vision/Synthetic Vision Simulation

- The purpose of this simulation experiment was to evaluate operational utility and pilot performance of several SVS/EVS display concepts.

- Six transport pilots from government research organizations, regulatory agencies, and airlines were recruited for the experimental evaluation.
- Display concepts evaluated were; (1) Head-down synthetic vision display with IR inset. (IR available at 0%, 20%, 40%, 60%, 80%, and 100% transparencies, pilot selectable); (2) Head-down synthetic vision display plus IR HUD; (3) Head-down synthetic vision display with threat icons provided by object detection icons; (4) Head-down synthetic vision display plus separate head-down IR display
- Results indicate that, for monitoring purposes, the use of a separate head-down display appears promising. It is not clear if adding performance data would affect the ability of the pilot not flying (PNF) to monitor the external scene.
- The display of the sensor image on a separate head-down display provided the best detection rates and accuracies, for these monitored approaches. The separate HDD provided only sensor data with no clutter. While the pilots complained about the lack of performance data, this may have enhanced their ability to see external threats. The head-down display was subjectively liked for the large size, the evaluation pilots down-rated it because of increased workload during the transition from instruments to visual references at minimums. They recommended adding symbology.
- The image insert may have been too small to provide a useful image. In addition the flight path icon was approximately the size as the DC-10 used in the runway incursion scenario. The evaluation pilots complained about clutter, small image size, and confusion between the SV and EV images.
- The use of icons may not improve detection performance sufficiently to outweigh potential certification complexity. As was pointed out by the evaluation pilots, icons convey no operational advantages allowing lower minimums. The evaluation pilot liked the icons because they eased detection ability, but disliked because they allowed no discrimination. In addition, icons offer no operational benefit (i.e. lower landing minima). The evaluation pilots recommended adding threat icons to the image displays.
- The image on the HUD was the display preferred by the evaluation pilots, but offered no advantage as a monitoring display.
- The head-down display location appears promising for the PNF to monitor the runway environment. Further evaluations should be conducted to determine if the addition of flight data will enhance or detract from this use.

4.23 Display Size and Terrain Texture Experiment

- This experiment will investigate the presentation of a synthetic scene (terrain database) to the pilot using different size displays utilizing pilot-selectable FOV and different terrain texturing patterns.

- The purpose is to confirm flight results from DFW and EGE flight tests and previous laboratory experiments.
- The experiment will be conducted in VISTAS III with approximately 16 test subjects (airline pilots).
- The planned scenarios for the experiment will be very similar to the EGE flight test. The circle to runway 07 approach will be flown with the KREMM departure. The pilot will fly the approach from either the size A, size X or HUD. Also, the texturing of the database will be either generic or photo. An additional run not flown at EGE will be a CFIT scenario where the flight guidance will intentionally direct the pilot into terrain.
- In addition to the 18 runs above, an additional 3 replications of flying a conventional display with the flight directors guiding to the same curved path and departure will be flown by each pilot. A final run will include a CFIT scenario. Each pilot will experience the CFIT scenario only once. The display conditions for the CFIT scenario will be distributed across the 16 subjects.
- The CFIT scenario may also incorporate a study of TAWS/VSD versus synthetic vision displays.
- In planning for mid-Spring, 2002

4.24 SVS Compellingness Study

- General areas of focus is to investigate SVS scene format and content issues, including use of eye-tracking capabilities to enhance human operator assessment, to evaluate display "compellingness" issues - making failures obvious, to examine issues of Attention switching - a major issue, as well as attention tunneling, and high perceptual workload.
- Goals include an investigation of "cognitive capture" of SVS display and "tunnel" pathway guidance as reflected by changes in eye-scan parameters, task performance, and subjective measures; to explore expected SA improvement using SVS displays of detection of anomalous (erroneous) flight path information; and to explore differences in SA and eye-scan patterns between integrated PFD-like information (size D display with SVS scene) and non-integrated (size A display with SVS scene) with separate airspeed, altitude, and vertical rate indicators
- Study is in planning

5.0 CONCEPT ASSESSMENT METRICS

5.1 RISK

Based on results to date, Table 5.1 indicates preliminary risk assigned to each of the concept elements and assessment criteria listed in Section 1. Risks were assigned by this document author, and do not yet represent a group consensus. Such a consensus will be obtained for future releases. A discussion follows in Section 6.

Table 5.1 Concept Risk Assessment

Element	Technical Risk	Ops Risk	Market Risk	Cert. Risk
Forward Looking Infrared (FLIR)	**Low**	**High**	**Med**	**Med**
Weather Radar (Potential SVS Modes)	**Med**	**Med**	**Med**	**Med**
Millimeter Wave Radar	**High**	**High**	**High**	**High**
Global Positioning System	**Low**	**Low**	**Low**	**Low**
Onboard SVS Data Base	**Med**	**Med**	**Low**	**Med**
System Integrity Monitoring	**High**	**High**	**Med**	**Med**
Terrain Feature Extraction	**High**	**High**	**High**	**High**
EVS Object Detection	**Med**	**Med**	**Med**	**Med**
Other Onboard Navigation Systems and Data Bases	**Low**	**Low**	**Low**	**Low**
Primary Flight Display, or imbedded display features	**Low**	**Low**	**Low**	**Med**
Navigation Display, or display features/pages	**Low**	**Low**	**Low**	**Med**
Head Up Display (option) with dedicated display features	**Med**	**Med**	**Med**	**Med**
Interface with Other Cockpit Displays, i.e., TAWS	**Low**	**Low**	**Low**	**Low**
Dedicated SVS Support Equipment and Crew Interface	**Low**	**Low**	**Low**	**Low**
Interface with Other Aircraft Systems	**Low**	**Low**	**Low**	**Low**

5.2 READINESS

Based on results to date in SVS experiments, as well as other known program results and technology, Table 5.2 indicates preliminary technology and implementation readiness levels assigned to each of the concept elements and assessment criteria listed in Section 1. Readiness levels were assigned by this document author, and do not yet represent a group consensus. Such a consensus will be obtained for future releases. A discussion follows in Section 6.

Table 5.2 Concept Readiness Assessment

Element	TRL	IRL
Forward Looking Infrared (FLIR)	7	4
Weather Radar (Potential SVS Modes)	2	2
Millimeter Wave Radar	6	2
Global Positioning System	9	9
Onboard SVS Data Base	5	3
Navigation Database Integrity	2	2
Surveillance Subsystem Integrity	7	3
Database Feature Elevation Integrity	6	2
System Integrity Monitoring	1	1
Other Onboard Navigation Systems and Data Bases	9	9
Primary Flight Display, or imbedded display features	5	3
Navigation Display, or display features/pages	5	3
Head Up Display (option) with dedicated display features	5	3
Interface with Other Cockpit Displays, i.e., TAWS	2	1
Dedicated SVS Support Equipment and Crew Interface	5	3
Interface with Other Aircraft Systems	5	3

6.0 CONCEPT ASSESSMENT DISCUSSION

The following are assessments of significance to each of the SVS Concept element areas, gleaned from results of experiments, and analytical studies to date.

6.1 General

The experiment and demonstration at Asheville near the beginning of FY 2000 afforded an excellent early look at the potential for SVS in augmenting path control and situation awareness in mountainous terrain. This experiment also provided significant material for the issues list in Section 7, as potential problem areas were identified in a real world operational environment and with relevant mission scenarios.

Initial simulation experiments and concept development helped narrow the scope of test for subsequent flight test, by identifying the likely range of operational acceptability in the extent of Primary Flight Display size and fields of view. The simulator was also very useful in developing flight test scenarios, timing, and procedures. Much of what was learned in the simulator with regard to pilot preference and overall flight operations was verified in the following flight test.

The study conducted on specific tools for situation awareness in SVS experiments provided a catalog of measurement tools for use in subsequent experiments, and will serve the team well in the future.

The team conducted an excellent workshop concerning the concept of SVS operations, which brought a significant user community presence into the project. Inputs from manufacturers, airline operators and managers, and regulatory agencies have added considerably to the concept, by identifying issues and potential benefits in future SVS-equipped operations.

A detailed study of future operational benefits for aircraft equipped with Synthetic Vision Systems concluded that benefits in operations in the contiguous United States were predominantly associated with low-visibility surface operations. Increased emphasis in this area will be devoted to future NASA research.

The flight test at Dallas offered an extensive operational look at early SVS configurations, in a flat terrain, culturally dense environment. A significant amount of quantitative and qualitative data was taken at Dallas, much of which is still being analyzed. Although problems were identified, in general there was widespread acceptance among airline Captains acting as Evaluation Pilots, of the overall SVS philosophy and concept. The presence of database imagery on the HUD and PFD was relatively well received, and pilots felt the information content and display methodology useable. Results from the experiment comparing photo-realistic versus generic terrain depiction indicate that, depending on size of display and nature of image information, each has advantages. Pilot control of the field of view on the PFD proved a useful tool in providing situation awareness during maneuvering or crosswind approaches. Larger display sizes were preferred, although each size was able, with appropriate fields of view, to perform the given tasks in the mission phases evaluated.

The flight test at Eagle Vail, Colorado, and simulation experiments leading up to the flight test, further matured operational concepts, exposing them to a real-world mountainous terrain environment. Tests showed dramatic improvements in pilot comfort and situation awareness with SVS configurations in this environment, and demonstrated utility of the concept elements in a variety of sizes and texture types. The presence of imagery on the HUD and HDD was well received (albeit preferred more on the head down displays). Results from this test will help narrow configurations and scenarios used for subsequent tests, to better focus on other critical SVS issues.

Industry and Government researcher input have greatly expanded the breadth of cataloged SVS issues. Future efforts will be devoted to deciding the best use of this issues catalog in steering future team research.

Future efforts will now be devoted to continued development of the SVS Concepts, with further evaluation of the concepts in a mountainous terrain environment at Reno, several simulation experiments and studies, and a further refinement of operational issues and concepts.

A specific discussion of SVS Concept elements and assessment metrics follows, by component.

6.2 Forward Looking Infrared (FLIR)

Efforts last Calendar Year have been devoted predominantly to design and installation issues associated with the planned installation of a FLIR sensor package in the NASA 757 test vehicle this Winter, to support Summer flight tests at Eagle/Vail.

The technical risk for FLIR is considered low – the technology is relatively mature. The methodology for operational employment of FLIR in a commercial and business aircraft environment is largely untried or unproven, however, and operational risk is therefore considered high. Assuming operational issues can be overcome, certification methodology will have to be developed, and operations benefits assessed to develop a marketing plan. These areas, then, are assigned medium risk.

Future plans include flight testing of a FLIR package in the NASA 757 test vehicle in the Spring of 2003, and an investigation of a British Aerospace (BaE) concept involving fused FLIR and MMWR images on a Head Up Display, for low visibility approach and landing path control.

The potential for FLIR utilization in low visibility surface operations for hazard detection is intriguing. Some effort in this area will be devoted to future NASA research.

6.3 Weather Radar (Potential SVS Modes)

Efforts this Calendar Year have been devoted predominantly to data collection and analysis. Weather RADAR data based algorithms may potentially provide benefits in two key areas: database integrity monitoring, and flight/ground object hazard avoidance. A key advantage of this scheme is that it uses equipment already present on commercial aircraft (though equipment availability of this non-critical system is an issue). The operational feasibility of use of existing RADAR data sources, combined with new algorithms, for these purposes, is largely untried in the commercial and business environment. Significant development and test is required to develop and prove utility of this concept prior to industry acceptance. Technical, operational, marketing, and certification risk of this component, therefore, is listed as medium.

6.4 Millimeter Wave Radar

No significant testing efforts involving Millimeter Wave RADAR (MMWR) have occurred this Calendar Year, other than limited discussions on potential future flight test opportunities. MMWR based algorithms may potentially provide benefits in two key areas: database integrity monitoring, and flight/ground object hazard avoidance. The technical risk for MMWR is considered high, though – the technology has never, to the author's knowledge, demonstrated an operationally acceptable scheme for augmenting strategic path control or hazard avoidance in the commercial and business aircraft mission environment. The methodology for operational employment of MMWR in a commercial and business aircraft environment is largely untried or unproven, as well, and operational risk is therefore considered high. Assuming operational issues can be overcome, certification methodology will have to be developed, and operations benefits assessed to develop a marketing plan. Given the likely high cost of manufacture, test, and certification of an operationally feasible MMWR system, these areas are assigned high risk. Future plans include an investigation of a British Aerospace (BaE) concept involving fused FLIR and MMWR images on a Head Up Display, for low visibility approach and landing path control.

6.5 Global Positioning System

Global Positioning System (GPS), even with differential corrections required for precision path control accuracy, is considered a relatively mature technology, with numerous off the shelf systems available, or being tested in their final forms. Though there are integrity, reliability, and criticality issues which remain before GPS is ready to support a fully implemented SVS-equipped airline fleet, the technology is mature enough that low risk categories have been assigned for technical, operational, marketing, and certification risk.

6.6 Onboard SVS Data Base

Significant efforts have occurred this Calendar Year in learning how to obtain source data for an SVS data base, and assemble it in simulation and flight test hardware and software. Issues associated with streamlining this process, and with the ability to guarantee accuracy, maintainability, availability, and integrity of the data base are currently being addressed, and so technical, operational, and certification risks are considered medium. Assuming the resulting infrastructure requirements won't result in prohibitive product costs, and that widespread area terrain elevation data will become readily available (the increasing availability of Shuttle Radar Topography Mission data is making this a reality), marketing risk for this component is considered low. NASA has also supported an Industry team to develop the data base production process.

6.7 System Integrity Monitoring

Given that certain conceivable failures of the data base could cause loss of an aircraft, the team believes this system to be critical to flight safety, and therefore is required to meet commercial critical reliability standards. It is further believed that, given the data collection methodology and the potential for data to change over time (man-made or natural terrain changes, tower construction, etc.), a necessity exists for a separate SVS component to assure data base integrity. The exact nature for this component, and required technology, is at present unknown (though potential candidates have been identified). Technical and operational risks, therefore, are considered high. Efforts this year have identified three sensor sources to support this function – Weather Radar, Millimeter Radar, and RADAR or LASER altimeter. Some testing has been accomplished to date, using Radar Altimeter data, which shows promise for this capability. Future tests will investigate terrain feature extraction, object detection, and terrain altitude sensing algorithms for the other sensors. Assuming costs for new required hardware and software to support implementation of the yet unidentified technology can be kept relatively low, marketing and certification risk for this area is considered medium. Preliminary System Integrity Monitoring algorithms were tested at Eagle Vail in the Summer and Fall of 2001, and will be tested again at Wallops and Reno in the Spring of 2003.

6.7 Other Onboard Navigation Systems And Data Bases

Though not representing new SVS equipment being added to an existing aircraft concept, SVS will certainly require information from other onboard aircraft systems, like attitude and heading from an Inertial Measurement Unit, altitude and airspeed from an Air Data Computer, cleared and desired path from a Flight Management System, etc. The nature of the interface between SVS and these systems, and the extent to which these associated functions are imbedded within SVS components, will depend on whether the SVS is a retrofit, or a new implementation. In any case, implementation details are envisioned to be workable for retrofit or new aircraft installations, and technical, operational, marketing, and certification risks are considered low in this area.

6.8 Primary Flight Display, Or Imbedded Display Features

Since the size of the Primary Flight Display, and available display surface for SVS display components will vary depending on whether the installation is in a new aircraft, or a retrofit solution, the SVS Project has investigated size and field of view issues on Primary Flight Displays, both in simulation, and in flight test. Results indicate that mission tasks can be performed across the gamut of anticipated display sizes, and so technical, marketing, and operational risks are considered low in this area. Incorporation of perspective terrain cues, as well as widespread commercial implementation of 3-D path cues on a commercial PFD are largely untried, however. Certification efforts associated with major changes in a Primary Flight Display are traditionally extensive, such that certification risk is considered medium here.

6.9 Navigation Display, Or Display Features/Pages

Flight and simulation testing this Calendar Year have used a Navigation Display format which is relatively mature, and generally well accepted by the evaluation pilots. The elements of this component are likely to be well integrated with existing hardware in the commercial and business aircraft mission environment. Testing to be accomplished in the next round of experiments will investigate new formats and features in this strategic display – specifically, advanced terrain depiction, 3-D perspective navigation and hazard avoidance cues, and exocentric display formats. New display formats have also been tested for surface operations, and future efforts will look at integration of the surface and airborne modes of operation. Future efforts will investigate continued development and optimization of the Navigation Display for SVS implementation. SVS elements of the Navigation Display will likely be combined on existing pages in a multi-function display, or be placed on dedicated pages, though the presence of SVS may dictate unconventional formats for optimum information depiction. It is likely that SVS components can be implemented which will augment mission performance without adverse impact, both on new and retrofit installations, and so technical, and marketing risks are considered low in this area. Certification efforts associated with major changes in this display are traditionally extensive, however, such that certification risk is considered medium here.

6.10 Head Up Display (Option) With Dedicated Display Features

Flight and simulation testing this year have used a Head-Up Display tailored and configured for SVS testing, with both raster image and symbolic elements. HUD implementation is also a candidate for SVS implementation in analog based cockpits. The philosophy to date has been to employ the HUD as an augmentation to path control and situation awareness, rather than as a Primary Flight Display. The use of an image on a HUD in this role, however, is largely untried previous to the present experiments (albeit well accepted by pilots to date). HUD utilization may be particularly appropriate for low-visibility surface operations. Overall, technical, marketing, operational, and certification risks are considered medium in this area.

6.11 Interface With Other Cockpit Displays, i.e., TAWS, TCAS

Efforts in this area have been predominantly limited to studies, though TAWS and TCAS were part of testing at EGE, in a relatively passive role. Further testing, concentrating on the CFIT role of TAWS and strategic SVS display, is planned at Wallops and Reno in the Spring of 2003. Implementation details are envisioned to be workable for retrofit or new aircraft installations, and technical, operational, marketing, and certification risks are considered low in this area.

6.12 Dedicated SVS Support Equipment And Crew Interface

This SVS component consists of equipment and controls necessary for crew interface to the SVS, i.e., mode controls, brightness and contrast controls, Flight Guidance interfaces (particularly mode transition and awareness), and flight path control workload alleviation features (autoflight modes). No specific studies were conducted this year in this area, though crew interface provisions were incorporated in all tests. Implementation details for support equipment and crew interfaces are envisioned to be workable for retrofit or new aircraft installations, and technical, operational, marketing, and certification risks are considered low in this area.

6.13 Interface with Other Aircraft Systems

No specific studies were conducted this year in this area, though aircraft system interfaces were required and incorporated in all tests. Implementation details for interfaces with other aircraft systems are envisioned to be workable for retrofit or new aircraft installations, and technical, operational, marketing, and certification risks are considered low in this area.

7.0 CRITICAL ISSUES

The following is a preliminary list of issues which have been identified as those which are appropriate to address in simulation, flight test, or laboratory studies in the SVS Project. Issues were obtained from Team consensus at a recent Issues Workshop, and from inputs from Element Leads who polled their element concerning critical issues. Issues are prioritized with respect to NASA risk and impact level, NASA research priority, and Boeing research priority (as Boeing was chosen as the Industry representative for issues identification). Levels are indicated as High (H) Medium (M) or Low (L) to indicate their relative criticality, assessed qualitatively, with respect to SVS goals and mission satisfaction, as well as resource availability. Initial priorities have been assigned for the majority of the issues, based on workshop issues. Issue priorities which are blank were those new issues subsequent to the workshop which have not as yet been prioritized. The list of issues, criticality, and priority should be reviewed by SVS Team members, and a consensus established as to the weighting assigned. This list will be updated at the next Concept Assessment Report update, to reflect Project decisions.

				Display Issues, General	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
1	M	M	H	Highway-in-the-sky/ pathway optimization	
2	H	L	L	Latency (transport delay)	0.300 sec seen in some display concepts
3	M	M	M	Clutter, HD Tactical	very important to address and get right
4	M	M	L	Clutter, HD Strategic	very important to address and get right
5	M	M	M	Clutter, HUD	
6	H	H*	M	Magnification / Minification	terrain that is minified to greatly could be hazardously misleading to the flight crew
7	H	L	H	Computing Power Required versus Available	
8	H	L	M	Architecture and sub-system integration	
9	L	L	M	Display Size	
10	L	L	L	Cross Cockpit Viewing	
11	M	L	M	Data / Memory Storage Capacity / Type	
12	M	L	M	Scene Generation Efficiency	
13	L	H	M	Flight path vector static and dynamic scaling - interaction with FOV	May impact display evaluation results- TUNE HUD
				Tactical Displays- PFD	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
14	L	L	L	Retro-fit optimum field of view (FOV) for small displays, size A and D.	
15	L	L	M	Forward-fit optimum field-of-view (FOV) for larger display formats.	
16	L	L	L	Display resolution/ pixel count issues.	
17	L	L	L	Varying FOVs based on flight segment or pilot selectability	Industry has not yet fully adopted variable or selectable FOVs

18	L	L	L	Manual or automatic control of FOV selection	
19	L	L	L	Integration with out-the-window scene – transition / training issues	
20	L	L	L	Unusual attitude recovery - due to turbulence, wake vortex encounter, hardware failure, asymmetries, icing; sloped skyline adopted as horizon? How is pitch and horizon (sky/ ground) information shown?	
21	M	L	H	4-D Navigation	
22	L	L	M	Pathway-only Computational Requirements	
23	H	H*	M	Pathway Implementation Strategy, Integration with CNS/ATM	Capstone manual entry of waypoints or pathway
24	L	L	L	Depiction of special use airspace (warning and restricted areas, temporary restrictions)	
25	M	L	H	HDD Luminance / Sunlight Readability, Contrast	LCD assumption lowers risk
26	L	L	L	Display control issues for PFD	
				Tactical Displays – Pathway Elements (Tunnel)	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
27				Pathway Type and Optimization (tuning with respect to bank angle and speed, for example)	
28	L	M	M	Tunnel Size, Shape, and Narrowing	
29	M	M	M	When to display tunnel, how to display vertically unconstrained paths, tunnel variations with phase of flight	
30	L	M	L	When to end the tunnel (before threshold and flare)	
31	L	M	L	Integration of flight guidance with tunnel (i.e., follow me aircraft, predictor, flight director)	
32	L	M	L	Integration of deviation scales with tunnel	
33	L	M	M	Tunnel capture guidance	
34	L	M	M	Transition to/from HUD tunnel and other display symbology	
35	H	H	H	Explore departure and missed approach pathway guidance to a waypoint where you can enter a tunnel	
36	H	H	H	Pathway issues - (yes, no, selectable) – major format issues	This needs to broken down into separate issues
				Tactical Displays – Head Up Displays	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
37	H	H	L	How to display information – opaque SV scene/wireframe	
38	L	H*	L	Minification of symbology and/or terrain during some phases of flight	
39	L	M*	L	EVS vs. SVS HUD Safety and Operational Benefit Comparison	
40	L	M	L	Integration with out-the-window scene during flight	
41	L	M	M	Integration with out-the-window scene on the surface	
42	L	M	H	Pathway and Guidance optimization on HUD during flight	
43	L	M	H	Pathway and Guidance optimization on HUD on the surface	
44	M	H	L	HUD Luminance / Sunlight Readability, Contrast	

				Strategic Displays (Navigation Display)	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
45	L	L	L	Display control issues for ND	
46	L	M	M	Integration with tactical displays (SV PFD and/or HUD)	
47	M	L	L	Integration with out-the-window scene – display transition / training issues	primarily surface
48	H	H	L	Terrain Clearance Depiction (ND/VSD inflight)	
49	H	H	H	Transition from flight to ground and back, with respect to taxi map displays	
				Pictorial Scene Information	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
50	H	H	H	Establish which scene cues are most important - includes perceptual cue requirements	
51	M	H	H	Generic terrain vs. generic with distance cue enhancements (e.g. “fishnet”, known introduced scene features or elements)	
52	M	H	M	Photorealism – where needed, problems of misleading distance/depth cueing	potential to nest photorealistic elements with generic ones
53	M	H	H	Terrain and object color, lighting, and shadow issues	
54	H	M	H	Database and/or sensed hazards (traffic, obstacles) depiction	
55	H	H	H	Issues of how to blend database and sensor information (integrity monitoring of surveillance, navigation, and database subsystems, including alerting)	
56	L	L	L	Sun angle conflicts between real / synthetic scenes, sun angle for night flying (?)	
57	M	M	M	Scene/Symbology Integration, I.e., color, salience, dynamics	
58	M	M	M	Displayed Terrain Elevation Grid (fishnet, if used) Spacing, configuration, color, style	may be phase of flight dependent
59	M	M	M	Texture Resolution Requirements, texture optimization, to include pattern flow from one element to the other, and mapping methodology	
				Database	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
60				Accuracy	
61				Maintenance (elevation, texture, aerodrome mapping, and object)	
62				Elevation Post Spacing Requirements	
63				Data merging (changes with altitude, different horizontal granularity or classes of data (feature, terrain, obstacle)	
64				DEM to DEM and DEM to reality comparisons	
65				Obstacle definition and identification	
66				Airport database surveying to RTCA SC-193 specifications	
67				Investigate quality of data from commercial and	

				governmental sources	
68				Database integrity (ICAO def – the data does not change)	
69				Certification	
70				To create a geospatial database prototype from the data acquired and used by the Synthetic Vision project that complies with the RTCA SC-193 recommendations.	
71				Sensor - DEM comparisons	
72				Real-time vs. post-processed database update processes	
				Limited Visibility Operations	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
73	H	H*	H	Strategy/evidence for how SVS can provide sufficient centerline guidance to takeoff in 300ft RVR or less (to improve upon HUD concepts that need guidance from a Type II/III localizer)	
74	H	H*	H	Strategy/evidence for how the database can substitute for visual acquisition of approach decision height criteria elements (approach light system, threshold, threshold markings, threshold lights, runway end identifier lights, VASI, touchdown zone or touchdown zone markings, runway or runway markings, runway lights)	
75	L	L	L	Strategy/evidence for how SVS is used to conduct non-ILS approaches.	don't require SVS to do this
76	H	H	H	Precision navigation for departures and approaches (integrating guidance formats and the terrain and obstacle database). Incorporate RNP, VNAV, LNAV. Strategy/evidence for how SVS can support lowering minima	
77	L	H	L	Strategy/evidence for how SVS can reduce CFIT	requested by Kathy Abbott. Include VSD and TAWS in baseline and SVS equipped config
				Surface Display Concept Integration, Including Airborne Transition	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
78	L	H	H	Integration, to include both tactical (PFD/HUD) and strategic (ND) displays. Build upon display work developed under AvSP's Runway Incursion Prevention Systems and TAP's LVLASO program. Investigate industry surface operations display concepts and incorporate into ND/PFD/HUD where appropriate. Investigate industry surface operations display concepts and incorporate into ND/PFD/HUD where appropriate.	
79	L	H	H	Develop tactical and strategic display switching strategies (gradual, instantaneous, certain altitude) from surface to air (departure) and from air to surface (landing) display concepts	
				Situation Awareness	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**

80	H	H	H	Display compellingness issues when discrepant information is present (pathway versus terrain)	cognitive capture. Potential FAA show-stopper
81	H	H	H	Attention switching – major issue, just because much information is present, can pilot switch to needed information – (several simulator pilots have missed seeing decreasing airspeed with SVS-like displays) – what about when tunnels, scenes, and traffic are displayed	cognitive capture. Potential FAA show-stopper
82	H			Can a set of overall requirements be established for the display system that includes the minimum requirements needed for both enhanced SA and performance?	(Ray Comstock cognizance)
83	M	H	L	Techniques for measuring SA	
				SVS Integration with Enhanced Vision Sensors	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
84	M	H*	L	Sensor image vs. Symbolic representation of sensor (FLIR, Millimeter wave radar, etc.) detected objects (runway, traffic, etc.) within the database. Where should sensor information be displayed, and how?	
85	L	M	M	Use of HUD (if available) - HUD / EVS Integration	
86	L	M	M	Safety and operational benefit comparison between EVS only, SVS only, and EVS/SVS concepts.	
87	L	L	L	Automatic Declutter of EVS (at decision height, for example)	
88	H	M	H	Environmental effects (phenomenon logy) on sensor performance	
89	L	L	L	Display Registration Requirements (parallax and pointing errors included)	
90	L	M	M	Head-Down Display of Imaging Sensor. Where should sensor information be displayed, and how?	
91	M	L	M	Imaging sensor cost, benefits, and feasibility of implementation - imaging sensor type	
92	H	M	M	Image and/or data fusion	
93	M	M	L	Sensor/Database scene interaction	
94	H	M	H	Image quality and artifacts versus sensor type	intrinsic to sensor, regardless of environment
				Integration of SVS with Terrain Awareness Systems (TAWS)	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
95	H	H	L	Best use of low res TAWS, wx radar, and high res SVS	Would we have TAWS and SVS of different resolution? Seems like they would be part of same system - Enhanced TAWS.
96	H	H	L	Obstacle presentation in TAWS	
97	H	H	L	Terrain awareness comparisons between TAWS and SVS. Consider approach, takeoff, missed approach. Use a Cali-like CFIT accident (descent)	Is this a comparison of old and new systems? It is if SVS actually becomes part of a TAWS system.
98	H	M	M	Safety and operational benefit comparisons between TAWS and SVS.	Is this a comparison of old and new systems? It is if SVS actually becomes part of a TAWS system.
				RIPS and Traffic Information	

	NASA Risk & Impact Level	NASA Research Priority	Boeing Research Priority	Issue / Question Title	Status/Comments
99				Reliable and accurate traffic data available onboard aircraft	ADS-B and TIS-B are leading candidate technologies. This data must include position information as well as heading and velocity information.
100				Effective, timely, and accurate runway incursion alerting algorithms	provide alerts only when necessary and do not generate false or nuisance alerts.
101				Determination of the effect on ATC operations of providing runway incursion alerting directly to the flight crew through generation of alerts onboard aircraft.	
102				Determine procedures for using RIPS in the flight deck.	This is necessary for certification, especially for low visibility operations.
103				CPDLC for surface operations available at airports. This includes transmission of assigned taxi routes, hold short clearances, and route deviation alerts. Compare with pilot input or automatic generation of routing information.	
104				High integrity positioning information (e.g. LAAS) available at airports, including airport surface coverage to support operations on runways, taxiways, and gate areas. Impact of using only raw GPS and/or WAAS.	
105				Benefit of incursion alerting in the flight deck versus use of CDTI only. If crews use CDTI effectively, they will detect incursions themselves. Is the human probability of missed detection and false alarm better than an automatic system? For example, a multipath target that shows up on the runway may be "detected" by the alerting system and generate a false alarm, whereas a pilot will see it blink on/off on the display and disregard it.	
106				Land and Hold Short Operations	
				Human factors Issues for Flight Data integration with SV scene	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
107	H	H	M	How do operational requirements by procedure being flown (SID, missed approach, runway change, RNP, emergency), or flight phase (approach, departure, ground ops, enroute) dictate where information needs to be presented? Answering this question with quantitative data is needed for a good design of SVS NDs, PFDs, and HUDs.	Shouldn't forget that procedures could change if warranted by new technology.
108	H	M	M	Placement and format of airspeed information - mins, max, flap range, accel, decel info, scaling	Can we declutter?
109	H	M	M	Placement and format of altitude information – format, baro info, decision alt, transition alt, ground	Can we declutter?
110	H	M	M	Vertical Rate info – format, placement	Can we declutter?
111	H	M	M	Roll info – format, readability	Can we declutter?
112	H	M	M	Pitch info – relevant scaling, readability	Can we declutter?
113	H	M	?	Precision nav and landing guidance info (e.g. RNP)	What is issue?
114	H	H	M	Flight path vector – format to minimize obscuring scene	
115	H	H	M	How represent path reacquisition	
116	H	M	?	Waypoints - other Nav Info?	Issue needs to be determined

117	H	H	M	Traffic/weather - when to show? Format? (covered in separate research issue)	May have been covered earlier
118	H	H	H	Ground Ops information – what info to show, format to show (covered in separate research issue)	Needs to be broken into separate taxi-map issues
119	H	H	M	Depicting clearance changes in SV displays (runway change accompanied by a datalink of the command that results in a symbology shift; tunnel changes)	Also need issues concerning how to convey changes of clearance to aircraft
120	M	M		Unusual attitude recovery.	May be covered elsewhere
121	M	M		Unusual attitudes due to: turbulence, wake vortex encounter, hardware failure, asymmetries, icing	May be covered elsewhere
122	H	M	M	will sloped skyline (e.g. mountains) be adopted as horizon?	Can we get accurate horizon depiction?
123	M	NA	?	Pitch ladder must handle – guidelines exist	Need to determine the issue here
124	M	M	L	Scene features in attitude recovery? Turn off?, provide terrain grid info?	Need to determine the issue here
125	M	NA	?	Guidance info?	Need to determine the issue here
126	H	H	M	Flight Path Vector Use/Tuning (with display size)	Need to expand issue explanation
127	M	M	M	Attitude Symbol Use	Need to determine the issue here
128	M	M	M	Pitch Ladder Optimization	Could reduce clutter
129	H	H		Cognitive Capture	May be covered elsewhere
				Failure of information; Backup instrumentation/Reversionary modes)	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
130	M	M	L	failure flags / removal of info issues	
131	M	M	L	disagreement / erroneous information – is it misleading, is it detectable	
132	M	M	M	Failure of display - migration strategy	
133	M	M	M	When it fails, can I revert to something else?	
				Utilization of Advanced Display Media	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
134	H	L	L	Off-axis information presentation	Should be very rare event.
135	H	H	M	HUD (collimated/non-collimated, color, wide FOV, stereo)	FOV and Color could be issues
136	M	H	L	Head-mounted displays (glasses, mounted onto David-Clark headset, etc.)	Some day, but not yet for Boeing Commercial.
				Format of Traffic and Weather on Tactical and Strategic Displays	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
137	H	M	L	Accuracy Requirements for CDTI	
138	H	H	L	CDTI symbols on ND and possibly on PFD/HUD	
139	H	H	L	TCAS symbols on ND and possibly on PFD/HUD	
140	H	H	L	Icon vs. symbol portrayal of traffic on PFD/HUD. In other words, do you draw an icon of a plane or show CDTI symbol on PFD/HUD	

141	M	M	?	Investigate AWIN tactical and strategic display concepts for weather presentation	
142	M	M	L	Investigate how to present info on ND with weather radar mode and TAWS mode	
143	M	M	M	Investigate how to present weather info on PFD/HUD	This would include general category of airspace to avoid, how to identify areas, how to symbolically present areas on SVS.
144	M	M	H	Investigate including information on runway conditions, wind shear, rime icing zones, hazards, etc.	This should apply to both air and ground operations
				Other Issues	
	NASA Risk & Impact Level	**NASA Research Priority**	**Boeing Research Priority**	**Issue / Question Title**	**Status/Comments**
145	M	M	H	Mixed Equipage problems - For an Airline; with ATC	assuming this has to do with how to achieve benefits form SVS/tunnel during transition from
146	M	M	M	Maintenance / updates to database - obstruction updating; updating a/c system database, database integrity	
147	H	H	M	Runway Incursion Prevention, Conventional vs. SVS Displays	Assumed the issue here is to identify the benefits of a taxi-map display for preventing incursions. At a general level this seems to already be well accepted.
148	H	H	L	EVS vs. SVS Head-down Safety and Operational Benefit Comparison	The Boeing trade study addresses the respective roles of SVS and EVS
149	H	H	L	SVS HUD vs. SVS Head-down	Boeing is not presently considering SVS on the HUD
150	H	H	H	DEM Density Requirements - What's Required Where? Transitions between DEM Levels	
151	H	H	H	Range/Altitude Judgment Techniques (Landolt C Wireframe Overlays, etc.)	Optimizing an SVS display to give pilots maximum situational awareness
152	H	H	L	Airborne Traffic Symbology - TCAS vs. CDTI; Icon vs. Symbol vs. Both	
153	H	H	H	Ground Traffic Symbology (Icon vs. Symbol vs. LVLASO Tag)	Best portrayal of symbology for taxi-maps both HUD and HDD are important.
154	H	H	L	Sensor Image vs. Icon - Runway (Image vs. Wireframe); Detected Object (Image vs. Icon vs. Symbol)	Big issue here is ability of computer vision systems to accurately ID objects very quickly. Human vision still has a strong advantage here I believe. There are also some thorny cert issues I suspect.
155	M	M	L	Pathway (yes, no, selectable) - format issues	Pilot selectability of path is low right now
156	M	M	L	How represent path reacquisition when cannot see path / re-routing issues	Don't think there will be any problem coming up with a workable design for this.
157	M	L	M	Maintenance of enhanced sensors - Cleaning, alignment, deicing, etc.	
158	M	M	M	Integration Issues - cockpit integration, display integration, image/symbology integration	
159	M	M	L	Operational Issues - two pilot operations	
160	H	M	M	Evaluation Issues - test techniques, test scenarios, simulation of degraded visual conditions, simulator considerations, flight simulating instrument conditions, flight simulating degraded visual environments, flight in actual conditions	Evaluations need to be meaningful (test the real issues) and reliable. Unfortunately this can be a problem.
161	H	H	H	SVS Operational Credit (eg., taxi / takeoff minima, LAHSO)	

162	H	M	M	Pathway benefits on parallel runway approaches	Boeing has preliminary description of this benefit. Further quantification may be needed - depending on audience requirements.
163	H	M	M	Reduced spacing benefits	Boeing has preliminary description of this benefit. Further quantification may be needed - depending on audience requirements.
164	H	M	M	ATM and enroute operations benefits and applications to reduce bottlenecks	Boeing has preliminary description of this benefit. Further quantification may be needed - depending on audience requirements.
165	H	L	M	Application of existing work in capacity to pathway utilization	Workers in SVS/Tunnel area must be familiar with concepts and existing work.
166	H	L	M	Benefits in noise abatement procedures	Boeing has preliminary description of this benefit. Further quantification may be needed - depending on audience requirements.
167	H	H		Integration of SVS with EGPWS and VSD, in CFIT prevention	
168	H	L	M	Benefits in new routing, with pathways	Boeing has preliminary description of this benefit. Further quantification may be needed - depending on audience requirements.
169	H	L		Operational efficiency benefits with pathway	This needs a more complete definition. Boeing has preliminary description of this benefit. Further quantification may be needed - depending on audience requirements.
170	M	L	M	Reduced ATM workload with pathways	
171	M	L	M	Benefits in training with flight path displays	Boeing has preliminary description of this benefit. Further quantification may be needed - depending on audience requirements.
172	L	L	L	Benefits in route rehearsal with SVS displays	
173	M	L	M	Communications capability for ADS-B, for use with pathways	
174	M	L	M	GPS requirements versus capabilities	
175	H	M	H	Infrastructure changes required for pathway implementation	
176	H	H	M	Taxi map benefits, including LAHSO	Boeing has preliminary description of this benefit. Further quantification may be needed - depending on audience requirements.
177	H	L	M	Ground capacity benefits	Boeing has preliminary description of this benefit. Further quantification may be needed - depending on audience requirements.
178	H	M	M	Technology readiness for taxi map displays	This must be parsed according to taxi-map component.
179	H	H*	H	Operational benefits for converging approaches and parallel approaches/departures, circling approaches.	
180	H			Increases in SA – look at different facets of SA, including spatial, systems, etc;	
181	L	L	L	Evaluate pilot workload as compared to conventional FD	
182	L	H	L	Operational benefits of using HUD with terrain and/or aerodrome database during flight	Boeing may not place terrain on HUD during flight
183	L	H	H	Operational benefits of using HUD with terrain and/or aerodrome database for surface operations	
184	H			Increases in SA – look at different facets of SA, including spatial, systems, etc;	

185	M			Effect on pilot workload as compared to conventional ND	

8.0 SUMMARY

Last Calendar Year has seen substantial progress in the maturing of an SVS Concept with the potential for meeting the goals of the Gore Commission in the area of Controlled Flight Into Terrain, as well as providing significant operational and marketing benefits to commercial and business aircraft owners and operators.

A substantial number of studies and experiments have been conducted last year, which have provided a significant quantity of data addressing existing SVS issues, and generating many new ones. Much follow-on effort is scheduled for Fiscal Year 2002 and 2003. A catalog of these studies and their significance has been presented in this document.

A list of prioritized issues has been presented in this document, to help guide future studies and experiments. This list is expected to be modified and expanded by the Project team, as results from experiments, studies, and discussions become available.

A list of SVS component risk and readiness has been presented here, to help guide the focus of future efforts. Results indicate that FLIR, Millimeter RADAR, and System Integrity Monitoring are high risk areas, given the presented metrics. Technical and Implementation Readiness Levels of SVS components indicate a wide range of readiness, with Weather RADAR modes, System Integrity Monitoring, and TAWS Interface listed as particularly low in both.

An update to this document will be prepared at the end of Fiscal Year 2002, which will present updates to experiments and studies, issues, and metrics.

9.0 ACRONYMS

ADC	Air Data Computer
ADS/B	Automatic Dependent Surveillance/Broadcast
AHRS	Attitude Heading Reference Set
ARINC	Aeronautical Radio Incorporated
ASDE	Airport Surface Detection Equipment
ASIST	Aviation Safety Investment Strategy Team
ATC	Air Traffic Control
ATM	Air Traffic Management
AvSP	Aviation Safety Program
AWIN	Aviation Weather Information
BaE	British Aerospace
CaB	Commercial and Business
CAWS	Central Alert and Warning System
CCD	Charge Coupled Device
CD	Compact Disc
CDTI	Cockpit Display of Traffic Information
CFIT	Controlled Flight Into Terrain
CHR	Cooper Harper Rating
CIRT	Certification Issues Resolution Team
CONOPS	Concept of Operations
CPDLC	Controller Pilot Datalink Communications
CRT	Cathode Ray Tube
CY	Calendar Year
DEM	Digital Elevation Model
DFW	Dallas/Fort Worth Airport
DGPS	Differential Global Positioning System
DIME	Database Integrity Monitoring Equipment
DoD	Department of Defense
DTED	Digital Terrain Elevation Data
EADI	Electronic Attitude Direction Indicator
EGE	Eagle/Vail Airport (Eagle County Regional Airport)
EFIS	Electronic Flight Information System
EGPWS	Enhanced Ground Proximity Warning System
EHSI	Electronic Horizontal Situation Indicator
EMM	Electronic Moving Map
EVS	Enhanced Vision Systems
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FBO	Fixed Base Operator
FD	Flight Deck
FLIR	Forward Looking Infrared
FMS	Flight Management System

FOV	Field of View
FY	Fiscal Year
GB	Gigabytes
GBS	Ground Based System
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HDD	Head Down Display
HDTV	High Definition Television
HFOV	Horizontal Field of View
HMD	Head Mounted Display
HSALT	Hold Short and Landing Technology
HSR	High Speed Research
HUD	Head Up Display
ID	Identify
IDS	Integrated Display System
IFF	Identification Friend or Foe
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
IOD	Image Object Detection
IRL	Implementation Readiness Level
IRU	Inertial Reference Unit
LAAS	Local Area Augmentation System
LAHSO	Land and Hold Short Operations
LaRC	Langley Research Center
LASER	Light Amplification through Stimulated Emission of Radiation
LCD	Liquid Crystal Diode
LIDAR	Light Detection and Ranging
LMI	Logistics Management Institute
LNAV	Lateral Navigation
LVLASO	Low Visibility Landing and Surface Operations
MB	Megabytes
MCHR	Modified Cooper Harper Rating
MHZ	Megahertz
MMWR	Millimeter Wave RADAR
NASA	National Aeronautics and Space Administration
ND	Navigation Display
NGS	National Geodetic Survey
NIMA	National Imagery and Mapping Agency
PC	Personal Computer
PFD	Primary Flight Display
PID	Pilot Information Display
R&D	Research and Development
R/A	RADAR Altimeter
R/C	Rockwell Collins
RADALT	RADAR Altimeter

RADAR	Radio Direction and Ranging
RAM	Random Access Memory
RIAAS	Runway Incursion Advisory and Alerting System
RIPS	Runway Incursion Prevention System
RIRP	Runway Incursion Prevention System
RNP	Required Navigational Performance
RSM	Runway Safety Monitor
RTA	Runway Traffic Alert
RTCA	Radio Technical Commission for Aeronautics
RVR	Runway Visual Range
SA	Situation Awareness
SAE	Society of Automotive Engineers
SF	Stopping Factor
SID	Standard Instrument Departure
SV	Synthetic Vision
SVDC	Synthetic Vision Display Concepts
SVS	Synthetic Vision System
SVSRD	Synthetic Vision System Research Display
SXGA	Pixel Resolution of 1024 by 768
TAP	Terminal Airport Productivity
TAWS	Terrain Awareness System
TCAS	Traffic Collision Avoidance System
TIFS	Total Inflight Simulator
TIS-B	Traffic Information Services - Broadcast
TRL	Technology Readiness Level
USGC	United States Geological Survey
VASI	Vertical Approach Slope Indicator
VFR	Visual Flight Rules
VISTAS	Visual Imaging Simulator for Transport Aircraft Systems
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation
VSD	Vertical Situation Display
WAAS	Wide Area Augmentation System
Wx	Weather
WxR	Weather RADAR

10.0 REFERENCES

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